2007

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Recommended Citation
Ganz, David J.; Saah, David S.; Barber, Klaus; Nechodom, Mark (2007). Fire behavior modeling to assess net benefits of forest treatments on fire hazard mitigation and bioenergy production in Northeastern California. In: Butler, Bret W.; Cook, Wayne, comps. The fire environment--innovations, management, and policy; conference proceedings. 26-30 March 2007; Destin, FL. Proceedings RMRS-P-46CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. CD-ROM. p. 143-157.

Fire Behavior Modeling to Assess Net Benefits of Forest Treatments on Fire Hazard Mitigation and Bioenergy Production in Northeastern California

David J. Ganz[1], David S. Saah[2], Klaus Barber[3], and Mark Nechodom[4]

Abstract—*The fire behavior modeling described here, conducted as part of the Biomass to Energy (B2E) life cycle assessment, is funded by the California Energy Commission to evaluate the potential net benefits associated with treating and utilizing forest biomass. The B2E project facilitates economic, environmental, energy, and effectiveness assessments of the potential public benefits associated with: (1) various options for treatment, disposition, and utilization of forest biomass and (2) energy production from biomass produced by forest remediation activities. The study models forest conditions, fire behavior and fuel changes over a 40-year period, under three fuel treatment scenarios: no treatment; harvest and thinning on industrial private lands; and a range of prescriptions on industrial private and public multiple use ownerships. Effects of three fuel treatment scenarios are evaluated on fuel treatment effectiveness, economic feasibility, energy production supported, ecosystem impacts, and the location and capacity of modeled biomass facilities. The B2E project is novel in its scale of analysis, modeling the landscape effects of fire and treatments on 2.7 million acres of forest and brushland in the northern Sierra Nevada. This landscape represents high-hazard fuel areas, a broad range of ownerships, diverse habitats, complex infrastructure, and other values at risk. With 50 percent public multiple use and 17 percent industrial private lands, this landscape provides a unique opportunity to evaluate the effectiveness of Strategically Placed Area Treatments (SPLATs) and compare them with industrial private thinning and harvest. With average pretreatment biomass levels of 79 bone-dry tons (bdts) per acre, the private treatments removed an average of 31 bdts/acre while SPLATs removed an average of 24 bdts/acre. Wildfire modeling of these treatments showed a 6 percent reduction in the number of acres burned from private treatments and a 22 percent reduction from both private and SPLATs on public lands. While the ownerships, forest type, density, and slope dictated the type of treatment prescriptions, the spatial arrangement of treatments has a greater impact on their ability to change fire intensity and extent than the prescription applied.*

Introduction

California's wildlands and forests have accumulated an excess of small diameter woody material, or biomass. Fire suppression over the past century, combined with intensive forest management and a generally warmer and wetter climate, have led to increasingly dense vegetation. When wildfires occur, the heavy accumulation of biomass often makes those fires larger and more severe. The increase in forest biomass threatens public health and safety, watersheds, and wildlife habitat with unacceptable losses to wildfire. Public land management agencies and local landowners are focusing their efforts on thinning forests to reduce wildfire risks and to make them more resilient

In: Butler, Bret W.; Cook, Wayne, comps. 2007. The fire environment—innovations, management, and policy; conference proceedings. 26-30 March 2007; Destin, FL. Proceedings RMRS-P-46CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 662 p. CD-ROM.

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to insects and diseases. These forest thinnings produce significant volumes of biomass as a waste product. Because this material currently has little commercial value, most agencies and landowners are faced with the expense of disposal by burning, chipping, and spreading, or hauling to a remote disposal site. Using forest biomass to generate electrical power is another disposal option. However, at this time, the costs of removing forest biomass to generate electrical power are generally higher than the costs of generating electricity from traditional sources, such as natural gas.

The social and environmental benefits of using forest biomass to generate electrical power are potentially substantial. In 1999, a major study conservatively placed the value of environmental benefits associated with biomass energy production in the United States at 11.4 cents per kilowatt-hour over and above the retail value of the energy generated (Morris 1999). In this study, the use of biomass from in-forest treatments is the least developed analysis, due in large measure to a lack of data and other analytical studies. While many studies have concluded that overall benefits of biomass energy production substantially outweigh costs, researchers face considerable challenges in quantifying the relevant economic values, particularly the benefits. A more accurate accounting of costs and benefits for forest biomass-to-energy strategies is needed to develop coherent policies that link forest health management, fuel loading reduction, and energy production.

Current inventory information indicates that in-forest fuels reduction may provide one of the largest sources of biomass fuel for power production in California. Removal of excess biomass from California's wildland areas to achieve public safety and environmental benefits could theoretically produce more than 30 million bone-dry tons (bdt) of biomass annually, of which approximately 18 million bdt would come from commercial and noncommercial forest management (CEC 1992; Shelly and others 1998; Kadam and others 1999). Assuming that this volume of biomass could be environmentally and economically available, it would comprise nearly eight times the biomass volume from all sources currently consumed for biomass power production in California (Morris 2002). The potential for power production would be substantial: 30 million bdt could produce more than 3,000 megawatts of power. Current biomass power production in California stands at about 650 megawatts annually, with a total capacity of approximately 750 megawatts. Biomass energy contributes 15 percent of the renewable power currently produced in the State, but has the potential to provide many times more (Morris 2002).

Life Cycle Assessment Approach

One approach used to identify and quantify the costs and benefits of biomass energy production is through a life cycle assessment. A life cycle assessment, or LCA, models the environmental impacts and related economic values associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment. Decisionmakers can use LCA models to evaluate opportunities to reduce negative environmental impacts and achieve economic efficiencies. LCA is a systematic analytical method used to quantify the benefits and drawbacks associated with the entire life cycle of a product. In LCA, all stages of a product's life are analyzed, from the extraction of raw materials needed to make the product through final product distribution. An LCA is ideal for comparing new technologies with existing technologies to identify overall costs and benefits in terms of economic, environmental, and energy effects.

The Pacific Southwest Research Station of the U.S. Department of Agriculture, Forest Service is working with the California Energy Commission's Public Interest Energy Research Program; the University of California at Davis; energy, forestry, and environmental consultants; and several State and Federal agencies to construct a cradle-to-grave forest biomass LCA model. The model, called the Biomass to Energy (B2E) LCA model, will be used to identify and analyze social, economic, and environmental costs and benefits of using forest biomass to generate electrical power.

Study Objectives

The objective for the Biomass LCA Project is to develop a comprehensive economic, environmental, and energy LCA model that can be used to evaluate the potential net public benefits associated with treating and utilizing forest biomass. This computer-based model will be designed to facilitate economic, environmental, energy, and effectiveness assessments for the potential public benefits associated with (1) various options for treating, disposing, and utilizing forest biomass, and (2) electricity production from forest remediation biomass

The model will require synthesis of existing studies and additional research to populate individual modules. A wide range of research and peer-reviewed data will be incorporated into the model, such as wildlife habitat impacts; costs of vegetation management, collection, processing, and transport of biomass materials; air and water quality impacts and benefits; changes in wildland fire behavior and impacts; and so forth. Model users will be able to game out different options (or scenarios) within the various modules, and to change modeling assumptions such as forest remediation prescriptions, transportation distances, types of equipment used, biomass generating technologies, and so forth. Ultimately, the model will be used to explore opportunities for converting forest biomass to electricity, based on economic viability, environmental impacts, and energy efficiency. It will also allow policymakers to evaluate the effectiveness of alternative forest biomass management policies in meeting public goals, stakeholder needs, and government regulations.

Study Site Selection

One important risk in complex environmental modeling concerns the degree of generality one assumes about the impacts of the unit processes within the model. To increase the accuracy of the modeling assumptions and impacts, the LCA project team will select specific geographic locations that correspond to the kinds of forest remediation needs in California. Each location will represent a different landscape archetype. The team will draw data from these selected areas to resolve fuzziness in the model, test assumptions, and provide opportunities to "ground truth" the model. Selection of the number and kinds of landscape archetypes was a key challenge early on in the project. Possible criteria for selecting areas include the following: (1) vegetation condition, (2) human population density, (3) sensitive ecological systems (habitats), and (4) existing infrastructure-related opportunities (for example, roads to provide access to treatment areas and transport materials from treatment sites) (table 1).

Table 1—B2E landscape archetype selection criteria.

Criterion	Specifics
High-hazard Fuel	FRCC3 fuel loading over a substantial portion of the landscape
Ownership Mix	Must have a reasonable mix of Public Multiple Use (PMU), Public Conservation and Recreation (PCR), Industrial Private Forestry (IPF), Non-industrial Private Forests (NIPF)
Human Settlement & Assets Capital Assets	Must have substantial areas of WUI A reasonable number of key infrstructure assets, such as dams, power line corridors, etc.
TES/SSC habitat	Habitat at risk of wildfire for several species of concern
Data Quality	Data available in several categories required by the model (e.g., private land use, WUI described, habitat (WHR) mapped, Fuel loading mapped, etc.)
Landowner/Agency Interest	Demonstrated interest in working with the B2E Project from public agencies, communities, environmental NGOs and private sector industries
Current Management	Baseline conditions, fire histories and current vegetation management prescriptions must be described and ideally mapped
Geographic Scope	Must be of sufficient size to measure changes in large-scale impacts, such as carbon cycling, habitat change across populations of T&E species or cumulative watershed effects
Representative Ecoregion	Must represent landscape characteristics of diverse forest/chaparral dominated ecoregions in California

The B2E LCA Beta model, selected as a landscape archetype using the criteria described above, is novel in its scale of analysis, modeling the landscape effects of fire and treatments on 2.7 million acres of forest and brushland in the northern Sierra Nevada (fig. 1). The Beta landscape was originally chosen to represent high-hazard fuel areas with a reasonable mix of ownerships encompassing a broad range of infrastructure and other values at risk. This landscape represents high-hazard fuel areas, a broad range of ownerships, diverse habitats, complex infrastructure, and other values at risk. With 50 percent public multiple use and 17 percent industrial private lands, this landscape provides a unique opportunity to evaluate the effectiveness of Strategically Placed Area Treatments (SPLATs) and compare them with industrial private thinning and harvest.

The Beta landscape has more than 240 vegetation strata, or types of vegetative assemblages, ranging from lower elevation scrub and manzanita (for example, around Oroville Dam on the lower west side), to midelevation mixed conifer, to eastside pine and western juniper. Many of these vegetation types are in overstocked condition, with a Fire Regime Condition Class (FRCC) rating of 2 and 3.

Figure 1—Location and features of B2E Beta landscape.

Fire Modeling Strategy and Assumptions

The Biomass to Energy (B2E) Team has constructed a comprehensive forest biomass-to-electricity model, which has identified and analyzed the economic and environmental costs and benefits of using forest biomass to generate electrical power while changing fire behavior at the landscape level. Recognizing the urgent need for reducing "catastrophic" fires at a landscape level, the B2E Team identified a modeling strategy for depicting fire behavior changes on the landscape as a result of emerging forest remediation treatment opportunities. This modeling strategy depends on a series of assumptions, which will be described in the following section.

Fundamental to the assumptions of the B2E treatments is the concept of SPLATs as described by the research and fire behavior modeling of Mark Finney of the Missoula Fire Lab in the Rocky Mountain Research Station, USDA Forest Service (Finney 2001). Finney's research on optimized treatments reveals that how you spatially arrange fuel treatments across the landscape is much more important than how much of the area is treated. Using the fire behavior modeling software FARSITE and FlamMap, Finney and his colleagues at the Missoula Fire Lab have shown that treatments on only 20 to 30 percent of the landscape can be effective in reducing the threat of crown fires and other severe fire behavior if the spatial arrangement of the treatments interrupts the fire's rate of spread (fig. 2).

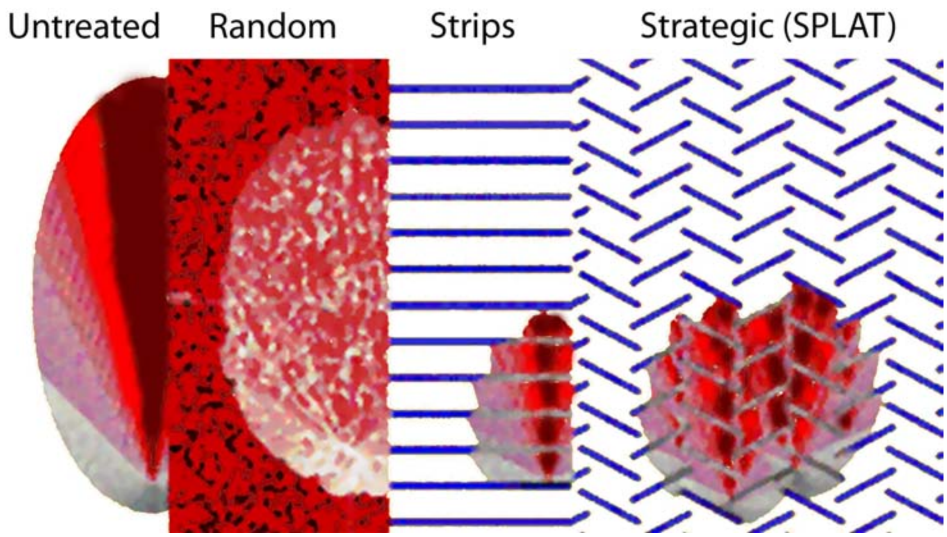

Figure 2—The effects of various fuel treatment patterns on fire size (adapted from Finney 2001). Left to right: homogenous fuel conditions (untreated), random treatments, complete overlap of parallel strip treatments, and strategic, slanted overlapped treatments.

For this study, fire behavior was summarized into three classes of severity to distinguish and report changes in wildfire effects across the B2E landscape (fig. 3). Burned areas were classified based on spatially explicit FlamMap (Finney and others 2006) model results of fireline intensity and the crowning behavior of the fires. The effects of wildland fire behavior on vegetation were tracked in the vegetation portion of the larger B2E-LCA project (domain), and overseen by the USDA Forest Service Region 5's Stewardship and Fireshed Assessment (SFA) Team. The severity of wildfire was assigned to three classes (nonlethal, mixed lethal, or lethal effects) depending on its flame length and fire type (ground fire, passive crowing fire, or active crowing fire). Fire severity determines the numbers of trees killed and the quantity of vegetation consumed by fire. Simulations were performed on a 10-year temporal sequence for 40 years with a series of fires taking place immediately at the beginning of each decade in each fireshed.

Fire Severity Classes		Fire Type (Crown Fire Activity)		
		Ground	Passive Crowning	Active Crowning
Flame Length (feet)	0.00-3.99	N	X	L
	4.00-7.99	X	X	L
	8.00-11.99	X	L	L
	12.00+	L	L	L

Figure 3—Classes of fire severity used in B2E fire modeling (Stewardship and Fireshed Assessment Team): (N) – Nonlethal, (X) – Mixed-lethal, (L) – Lethal.

The modeling strategy was to measure and treat changes in wildfire effects as expected value outcomes, reflecting average outcomes over long periods of 10 years or more. The team averaged probabilities of wildfire occurrence across space and time. The 10-year intervals over a 40-year timeframe for the fire modeling effort have been selected because this timeframe fits well with the economics that drive timber harvest (single entry at 20-year intervals for uneven aged management) as well as the life cycle of the technology being evaluated (biomass conversion plants are likely to become obsolete and depreciate after 20 years).

Modifying landscape-scale fire behavior when only a portion of the landscape can be realistically treated requires attention to layout. Mark Finney's research indicates that fire spread rates can be reduced, even outside of treated area, if a fire is forced to flank treated areas where fuels have been reduced. However, two criteria must be met for the strategy to be effective: (1) the pattern of treatments must be laid out in a manner that interrupts fire spread, and (2) prescriptions within the treatments must be designed to modify fire behavior.

Of course, forest management has to be conducted with multiple objectives in mind. The impact of fuel treatments on wildlife habitat, threatened and endangered species, and recreational opportunities are essential considerations. In addition, forest managers often have an opportunity to generate revenue through timber sales to cover or offset the costs of management activities. This means that optimal pattern for preventing wildfires is not a realistic option. The treatments are adjusted to protect sensitive wildlife habitat, reduce negative watershed effects, shape recreational opportunities, and capture timber volume to help pay for treating more areas.

Methods

This study was able to track the contribution of private and public land treatments toward modifying large-scale fire behavior by comparing the difference in fire behavior between three management scenarios:

- *Scenario 1* – No treatment: This scenario assumes no treatments on private or public lands, thereby providing a reference for the interaction of the environment and fire. Vegetation is grown across the beta landscape over the 40-year period, and the resulting fire effects are modeled. The scenario assumes no salvage harvest or reforestation after wildfires. When compared to scenario 2 (below), the no treatment scenario allows the team to track the contribution of private land treatments (including salvage) toward modifying large-scale fire behavior.
- *Scenario 2* – Industrial Private Forests (IPF) only: This scenario assumes treatments on private lands only; no treatments are assumed for public lands. On public lands, vegetation is grown from the current date and only fire effects are tracked, much as in scenario 1. It is assumed that the mix of IPF ownership managed under even aged and uneven aged management is 50-50 percent.
- *Scenario 3* – IPF and Public Multiple Use (PMU) combined: This scenario assumes the overriding goal is to achieve fire behavior modification at a landscape scale. Private lands are treated as under the same prescriptions as scenario 1 (IPF only), and PMU lands are treated using a variety of strategic approaches (defensible fuels profile zones and SPLATS).

Fire modeling outputs included the number of acres in three classes of fire severity, the number of burned acres with crown fire behavior, and flame lengths less than and greater than 4 feet. Historical fire occurrence was used to locate ignitions. Discrete ignition points at locations across the landscape were chosen recognizing that demographics, human activities, and climatic conditions will vary with time (fig. 4). This study used predetermined ignitions per decade instead of a random generator. Randomization of ignition locations did not yield the "catastrophic" events needed to measure differences between the three main treatment scenarios. While purely a means to the end, the rule sets generated for performing these three treatments across 2.7 million acres (table 2) have received attention for similar modeling ventures in California.

Results

With a no treatment weighted average biomass levels of 79 bone-dry tons (bdts) per acre, the private treatments removed an average of 31 bdts/acre while SPLATs removed an average of 24 bdts/acre (table 3). Downstream models are evaluating the effects of these three fuel treatment scenarios on economic feasibility, energy production supported, ecosystem impacts and the location and capacity of modeled biomass facilities. For the purposes of

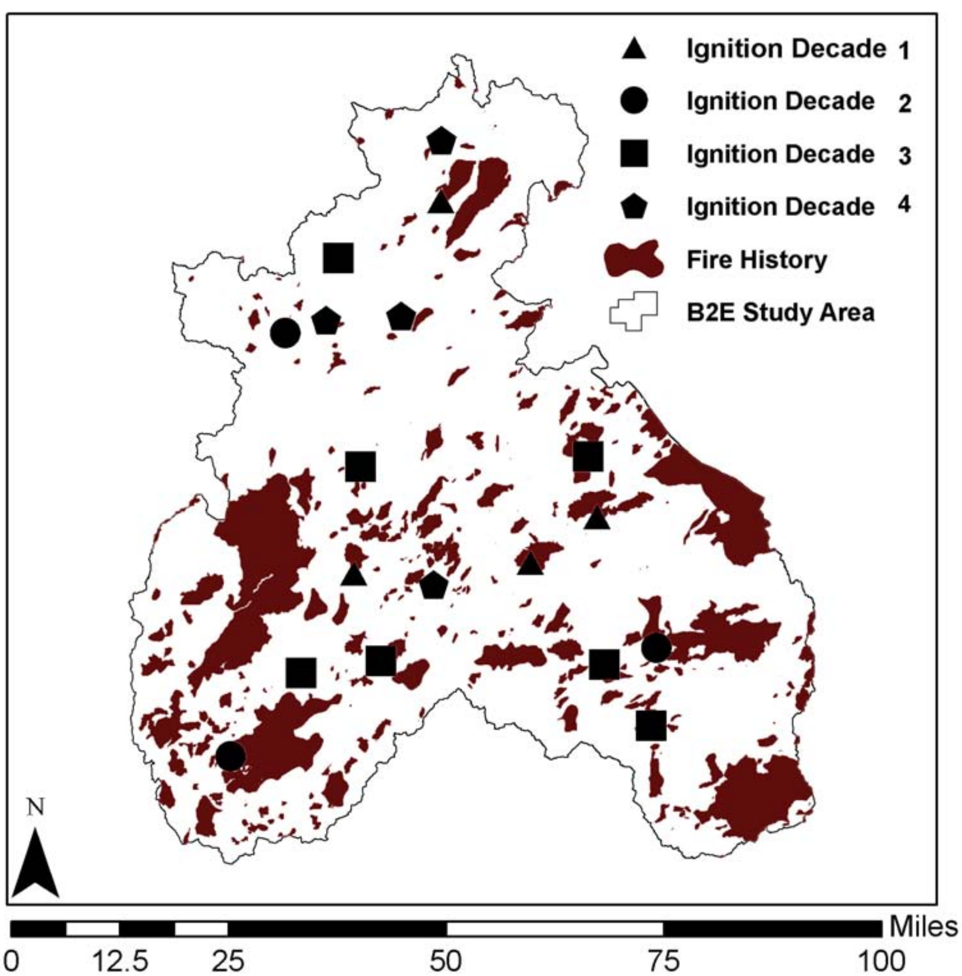

Figure 4—B2E Beta landscape fire history and ignition placement by decade.

Table 2—Treatment allocation rule base and logic.

Mgnt. Regime	Lands Applied to:	Treatment Cycle	Treatment Unit Size	Regime Code or ID	Per-1	Per-2	Per-3	Per-4	Rx Desc	Salvage
Wildland Fire Use	Public Conservation	n/a	n/a	n/a	n/a	n/a	n/a	n/a		no
Rx Fire [initial	Public-MU >50%	20-yrs	140-acres	31	Rx Fire		Rx Fire			no
				32		Rx Fire		Rx Fire		
Restricted Thin	Public-MU <50%	20-yrs	150-acre ave. SPLAT [Finney Herring Bone Psattern]	21	Initial Integ.Fuel s Treat		Maint - Integ.Fuels Treat		thin for fuels- retain 40% cc	yes
				22		Initial Integ.Fuels Treat		Maint - Integ.Fuels Treat		
			DFPZs as mapped under QLG [1/4mi fb]	23	Initial Integ.Fuel s Treat		Maint - Integ.Fuels Treat		thin for fuels- retain 40% cc	
	SMZ-IFL[1]	treated along with interesect unit	300-ft perin.	n/a	Initial Integ.Fuel s Treat		Maint - Integ.Fuels Treat		thin for fuels- retain 40% cc	yes
				n/a		Initial Integ.Fuels Treat		Maint - Integ.Fuels Treat		
Unevn-aged	IFL [1] all Slopes and IFL[2] w/SLp >50% only	20-yrs	140-acres	11	Selective Harvest		Selective Harvest		Thin for product [~5mbf/ac] & stand vigor	yes
				12		Selective Harvest		Selective Harvest		
	All NIFL Slp <50%	20-yrs	20-acres	11	Selective Harvest		Selective Harvest			no
				12		Selective Harvest		Selective Harvest		
Even-aged	IFL[2] slp <50%, mature	70-years	20-acres	1	Regen Harvest	PCT		ComThin	Regn Harvest-Clearcut	yes
				2,7		Regen Harvest	PCT			
				3,6	ComThin		Regen Harvest	PCT	comthin to a Ave. BA	
				4,5		ComThin		Regen Harvest		
	IFL[2] Plantations , <15yrs	70-years	as mapped	8	PCT		ComThin		percom thin to 150-160 tr/ac	no
No Treatment	all others	n/a	n/a	1-4	n/a	n/a	n/a	n/a		no

PMU Public Multiple Use
PCR Public Conservation-Recreation
IFL_U Industrial Forest Lands [1, 2]
NIFL Non Industrial Forested Lands
NON Others, Non Forested Lands, Urban
SMZ Streamside Management Zone.

this study, by comparing the difference in fire behavior between three management scenarios over the 40-year management trajectory, we can evaluate the contribution of private and public land treatments toward modifying large-scale fire behavior.

While the ownerships, forest type, density, and slope dictated the type of treatment prescriptions, we found that the spatial arrangement of treatments has a greater impact on their ability to change fire intensity and extent than the prescription applied. While we recognize that the optimal pattern for preventing catastrophic wildfires (or reducing their impacts) is not always a realistic option, we have modeled scenarios 2 and 3 with the necessary adjustments to protect sensitive wildlife habitat, reduce negative watershed effects, shape recreational opportunities, and capture timber volume under industrial private forest ownerships (that are both realistic in turns of net revenues and

Table 3—B2E pretreatment inventory and amounts of biomass removed by scenario and year (in BDTs/acre)

Scenario	Year	Inventory	Treatment
1: No treatment	2006	64	
	2016	73	
	2026	80	
	2036	86	
	2046	91	
	Average	**79**	
2: Industrial Private Forests (IPF) only	2006	64	30
	2016	69	35
	2026	73	28
	2036	76	31
	2046	79	
	Average	**72**	**31**
3: (IPF) & Public Multiple Use (PMU)	2006	64	28
	2016	67	34
	2026	70	23
	2036	73	26
	2046	75	
	Average	**70**	**28**
3b: (PMU) - SPLATS	2006	64	26
	2016	66	34
	2026	67	17
	2036	70	20
	2046	72	
	Average	**68**	**24**

yet protects their proprietary information). Many of these assumptions are depicted in the treatment allocation rule sets and logic described above.

Quantifying effectiveness of fire mitigation treatments is a challenge as there is no accepted system of measurement. Evaluations of fire hazard mitigation programs tend to focus primarily on the number of acres treated and treatment costs associated with mitigation without adequately assessing the benefits of these treatments. These programs also tend to focus on monitoring the total number of acres burned from 1 year to the next to determine efficacy of certain fire mitigation strategies (for instance, comparing DFPZs and/or SPLATs with traditional fuel break systems). Wildfire behavior modeling, especially with FlamMap, lends itself well to landscape comparisons (for example, pre- and posttreatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in treatment prioritization and landscape-level assessments such as the B2E Beta model. The B2E Beta wildfire behavior modeling of these three treatment scenarios showed a 6 percent reduction in the number of acres burned from private treatments and a 16 percent reduction from SPLATs on public lands (table 4). Scenario 3 had the overall greatest effect on the number of acres burned (that is, fire perimeters) with a 22 percent reduction from the no treatment scenario. For scenario 2, decade 2 had the greatest impact on reducing the fire perimeter with a 19 percent reduction in total acres (table 4). We expected to see a similar trend for reducing fire perimeters across all four decades but recognize

Table 4—Summary of B2E Beta Model burned acres by scenario and year.

Year	1: No treatment	2: Industrial Private Forests (IPF)	3b: (PMU)	3: (IPF) & (PMU)
2006	92,684	92,168	81,004	80,487
2016	60,153	48,616	51,383	39,846
2026	69,953	65,241	49,097	44,385
2036	76,543	75,758	68,582	67,796
Total Acreage	299,334	281,782	250,066	232,514
% Change from No TMT	0%	–6%	–16%	–22%

that differences existed due to modeling assumption and fire placements. These heightened effects for decade 2 were attributed to the location of the ignitions, higher proportion of private industrial ownership, and the topography within the fire perimeters.

As expected, scenario 1 generated the most acres burned with an average of 74,833 acres. While not all fires will achieve the same size, the burned acreage per decade averaged 67,802 acres for all three scenarios. Ignoring the small fires, the B2E Beta landscape's fire history on record (past 80 years) averaged around 65,000 burned acres per decade. The wildfire behavior modeling efforts for this B2E LCA Beta model have tried to mimic the fire history on record burning 65,000 acres in a variety of fire size and intensities with acres in each severity class approaching 30 percent based on work by Miller and Fittes (2006).

Evaluations of fire hazard mitigation programs tend to focus primarily on changes in the number of acres burned (since those are easiest to monitor). A modeling venture such as the B2E LCA Beta model allows us to evaluate the contribution of private and public land treatments toward modifying large-scale fire behavior using intensity as the change metric. Across all scenarios, 30.8 percent of the acres burned were characterized as nonlethal; that is, surface fires with flame lengths between 1 and 4 feet (table 5). The percentages of fire severity classes from the B2E wildfire modeling effort correspond well with Forest Service severity monitoring for the Sierra Nevada (Miller and Fites 2006).

These fire severity classes are important to the B2E LCA Beta modeling project because many of the downstream models are evaluating the effects of these three fuel treatment scenarios based upon these three classes. For

Table 5—Summary of B2E Beta Model severity class acres by scenario.

	Scenario			Summary	
Fire Severity Class	**1**	**2**	**3**	**Total**	**%**
N - nonlethal	81,471	82,160	86,586	250,216	31%
X - mixed lethal	136,887	125,156	98,560	360,603	44%
L - lethal	80,976	74,465	47,368	202,809	25%
Grand Total	**299,334**	**281,782**	**232,514**	**813,629**	**100%**

instance, fire consumption rates for canopy fuels and resultant wildfire emissions for green house gases are all modeled and calibrated to these fire severity classes.

As expected with the higher total number of acres burned, the percentages of acres with lethal and mixed-lethal fire severity classes were also highest in decade 2 (table 6). All three fire severity classes were favorably affected by applying both the private and public treatments over the four decades. Only decade 3 showed a decrease in the number of acres in the nonlethal severity class (3,880 acres) but that is due to the dramatic drop in total acres burned from implementing both public and private treatments in this particular decade with a positive change of 25,568 acres or 36.5 percent from the non-treated scenario 1 (table 4).

Table 6—B2E Beta Model severity class acres by scenario by year.

		Fire Severity Classes		
Scenario	**Decade**	**N**	**X**	**L**
1	1	36,579	33,176	22,929
	2	19,447	20,947	19,759
	3	19,296	31,691	18,965
	4	6,148	51,072	19,324
2	1	37,953	30,592	23,623
	2	21,491	13,208	13,917
	3	14,312	32,791	18,138
	4	8,404	48,566	18,787
3	1	37,889	24,740	17,858
	2	19,914	15,452	4,480
	3	15,417	18,496	10,472
	4	13,366	39,873	14,557

Despite a 6 percent positive effect on the number of acres burned, applying private treatments alone does not always result in a favorable effect on changing the fire severity. Decade 1's lethal severity class increased by 694 acres and decade 3's mixed lethal increased by 1,100 acres (albeit 827 acres of these can be attributed to a decrease in severity from lethal to mixed-lethal classes). Crown fire behavior in even-aged managed stand, especially during early stages of plantation development, can explain for these two increases in fire severity classes (out of 12 represented in table 6). Overall, the majority of the acres modeled in this effort demonstrated favorable impacts of implementing industrial private forest treatments with a decrease of 7 percent in the lethal severity class across the entire B2E Beta landscape.

Conclusions

Assuming that collection, processing, and transportation are economically viable, the conversion of forest biomass to useful energy becomes a critical economic and environmental issue. The B2E LCA Team has constructed a comprehensive forest biomass-to-electricity model, which has identified and analyzed the economic and environmental costs and benefits of using forest biomass to generate electrical power while changing fire behavior at the landscape level. The B2E wildfire behavior modeling of three treatment scenarios showed reductions in the number of acres burned and changes in intensity classes. Whether compared for the entire B2E Beta landscape or within perimeters of the 67,800 acres burned per decade, treatments applied to both public and private lands changed fire behavior and growth. The B2E wildfire modeling venture has demonstrated that treating public multiple use lands with SPLATs, albeit not nearly as strategically applied as originally intended by its designers, contributes more (percentage wise) than private sector treatments for modifying landscape-scale fire behavior. The goal of such modeling efforts is not to differentiate between public and private sector treatments, but rather, to improve our understanding of implementing forest treatments across ownerships to prevent catastrophic wildfires (or at least reduce their impacts). The next steps for improving the B2E wildfire modeling component of this B2E project will be to move to another landscape archetype using the criteria described in this paper and design a growth model for brush types that will complement the vegetation growth simulations over a 40-year timeframe.

The California Biomass to Energy project and other similar projects will help provide information about potential economic, energy, and environmental tradeoffs associated with various options for managing forest biomass and using forest biomass material to produce renewable energy. The results, findings, and conclusions of these efforts will help government organizations establish policies, legislation, incentives, and funding initiatives relative to biomass power, as well as assist private, academic, and government organizations in setting priorities and establishing plans for forest research and development programs.

Discussion

A primary assumption of the B2E fire behavior modeling approach is that SPLATs, as both a theoretical and an applied approach, will indeed fragment the fire-prone environment of the Beta landscape for the desired effect of reducing fire behavior, growth and/or severity. The modeled outcomes demonstrated in our results show a favorable effect from the spatial arrangement of treatments, but it is obvious that policymakers will need more empirical data to justify greater application of SPLATs on public lands. Recognizing this need, the USDA Forest Service and the Joint Fire Science Program have funded several empirical studies that are designed to demonstrate landscapes that have been treated for fuels with SPLATs, DFPZs, and other strategic approaches that can effectively change the behavior of wildfires. One such study currently producing empirical results is being performed at the Sagehen Experimental Forest by Dr. Scott Stephens and Dr. John Battles from the University of California at Berkeley (Saah and others 2006). Other studies have begun to report the efficacy of earlier treatments in reducing the effects of wildfires (for example, see Fulé and others 2001a,b; Finney and others 2005). In 2002, the Cone Fire on the Blacks Mountain Experimental Forest and funding from the Joint Fire Science Program provided Skinner and others (2004) with the opportunity to document changes in fire behavior on a landscape where fuels treatments had been conducted. Skinner and others (2004) stated, "In the case of both treatments the fire dropped quickly out of the crowns to become either a surface fire or die out upon entering the treated areas. The rapidity of apparent change from a high-intensity crown fire to a much lower-intensity surface fire may have significant implications for management of wildland/urban interface zones as well as wildlands in general."

As Mark Finney's research indicates, modifying landscape-scale fire behavior when only a portion of the landscape can be realistically treated requires attention to layout. We agree that the spatial arrangement of treatments is critical. On the B2E Beta landscape we noticed that strategic placement had a greater impact on fire intensity and extent compared to treatments themselves (dictated by ownership, forest type, density, and slope). Fire severity, as defined by the three classes, decreased by both private and public forest remediation treatments with a greater effect on public multiple-use lands. We were not surprised to find that the mass SPLAT implementation on public lands had a greater effect on fire behavior than the treating of private lands for commercial timber values. The downstream models utilizing these modeling outputs for further analysis are undoubtedly going to question the large-scale implementation and lack of strategic direction when SPLATs were applied to the B2E landscape. In our B2E LCA model, all stages of a product's life are analyzed, from the extraction of raw materials needed to make the product through final product distribution. In this LCA, biomass is the raw material (considered here as a waste product) and energy is the desired final product. The mass application of SPLATs on public lands to generate this raw material while positively reducing fire behavior, growth and/or severity (and subsequently reducing the emissions that would have been emitted by these fires), will either tip the balance for generating renewable energy from this waste product or drive up the costs of removing forest biomass due to the need for strategic planning and treatment implementation.

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